Jet Physics in Heavy Ion Collisions with Compact Muon Solenoid detector at the LHC

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Abstract. The status of CMS jet simulations and physics analysis in heavy ion collisions is presented. Jet reconstruction and high-p$_T$ particle tracking in the high multiplicity environment of heavy ion collisions at the LHC using the CMS calorimetry and tracking system are described. The Monte Carlo tools used to simulate jet quenching are discussed.

1. Introduction

One of the important tools for studying properties of the quark-gluon plasma (QGP) in ultrarelativistic heavy ion collisions is QCD jet production. Medium-induced energy loss of energetic partons, "jet quenching", should be very different in cold nuclear matter and in the QGP, resulting in many observable phenomena [1]. Recent RHIC data on high-p$_T$ particle production are in agreement with the jet quenching hypothesis [2]. However direct event-by-event reconstruction of jets is not available in the RHIC experiments. At the LHC, a new regime of heavy ion physics will be reached at $\sqrt{s_{\rm NN}} = 5.5$ TeV where hard and semi-hard particle production can dominate over the underlying soft events. The initial gluon densities in Pb + Pb reactions at the LHC are expected to be significantly higher than at RHIC, implying stronger partonic energy loss, observable in various new channels [3].

2. CMS detector

The Compact Muon Solenoid (CMS) is a general purpose detector designed primarily to search for the Higgs boson in proton-proton collisions at the LHC [4]. The detector is optimized for accurate measurements of the characteristics of high-energy leptons, photons and hadronic jets in a large acceptance, providing unique capabilities for "hard probes" in both pp and AA collisions [5]. A detailed description of the detector elements can be found in the corresponding Technical Design Reports [6, 7, 8, 9]. The central element of CMS is a 13 m long, 6 m diameter, high-field (4 T) solenoid with an internal radius of ≈ 3 m. The tracker and muon chambers cover the pseudorapidity region $|\eta| < 2.4$ while the electromagnetic (ECAL) and hadron (HCAL) calorimeters reach $\eta = \pm 3$ and $\eta = \pm 5.2$ respectively. A pair of quartz-fibre very-forward (HF) calorimeters, located at ± 11 m from the interaction point, cover the region $3 < |\eta| < 5.2$. In addition, the quartz-fibre calorimeter CASTOR covers the region $5.3 < |\eta| < 6.4$. The high precision tracker is composed of silicon pixel and strip counters and allows track momenta to be determined with a resolution better than 2% for tracks with p_T between 0.5 GeV/c and a few tens of GeV/c.

3. Jet production in heavy ion collisions at CMS

The following probes for studying jet quenching with CMS has been proposed:
- high-p_T jet pair production [10];
- jets tagged by a leading charged hadron or neutral pion [11];
- B-jets tagged by a leading muon [12];
- jets produced opposite a gauge boson in γ+jet [13, 14] and γ^*/Z^0+jet [15, 16, 17] final states;
- high mass dimuons from semileptonic B and D decays [18, 19] and secondary J/ψ [19];
- inclusive high-p_T particle spectra [20];
- energy flow measurements [21, 22]

Channel	Time=1.2×10^6 s, $\sigma_{AA} = A^2\sigma_{pp}$
jet+jet, $E_T^{\text{jet}} > 100$ GeV	4×10^6
jet tagged by $h^\pm/\pi^0$, $E_T^{\text{jet}} > 100$ GeV, $z > 0.5$	2×10^5
B-jet tagged by μ, $E_T^{\text{jet}} > 50$ GeV, $z > 0.3$	2×10^4

Table 1. Expected rates for some jet channels in a one month Pb + Pb run ($z = E_T^{\text{leader}}/E_T^{\text{jet}}$).

The dependence of these probes on event centrality (determined using very forward CMS calorimetry [23]) and their azimuthal distributions (the event plane can be reconstructed using energy flow in CMS endcaps [24]) will carry information about the properties of the QGP at the LHC. The event rates for some channels, including hard jets, in a one month Pb + Pb run (assuming two weeks of data taking and not including reconstruction and trigger efficiencies) in the CMS acceptance estimated with PYTHIA 6.2 [25] are presented in table 1.

4. Jet reconstruction with calorimetry

The main difficulty of QCD jet recognition in heavy ion collisions arises from the "false" jet background − transverse energy fluctuations coming from the high event multiplicity. In the CMS heavy ion programme, the sliding window-type jet finding algorithm has been developed [5, 3] to search for "jet-like" clusters above the average energy and to subtract the η-dependent background from the underlying event. Figure 1 shows the linear correlation between reconstructed (full GEANT-based simulation) and generated (PYTHIA 6.2) transverse energies of jets with cone radius $R = 0.5$ in Pb + Pb ($dN^\pm(y = 0)/dy = 5000$) and pp events. The purity of jet reconstruction, defined as the number of events with a true QCD jet divided by the number of events with reconstructed jets, becomes ~ 1 at 100 GeV (figure 2). Note also that the fine angular resolution, $\Delta\varphi \sim \Delta\eta \sim 0.3$ at $E_T^{\text{MCjet}} = 100$ GeV, less than the azimuthal size of a calorimeter tower. Further development of the jet reconstruction algorithm using tracker information for the jet energy correction is under way.

5. Charged particle tracking in jets

Track finding in heavy ion collisions is difficult due to the large number of tracks in an event. In addition to the primary tracks, the CMS tracker is occupied by secondaries produced by interactions with the detector material. The CMS track reconstruction algorithm, originally developed for pp collisions, is based on Kalman Filtering and includes seed generation, track propagation, trajectory updating and smoothing. In order to reduce the combinatorial background during track seeding in heavy ion collisions, the modified track finder also includes primary vertex finding and restriction of the vertex region [26]. The requirement for tracks to leave the tracker trough the outermost layer leads to a minimum transverse momentum cutoff of $p_T > 1$ GeV/c for the track to be considered reconstructable. Given this constraint, the track

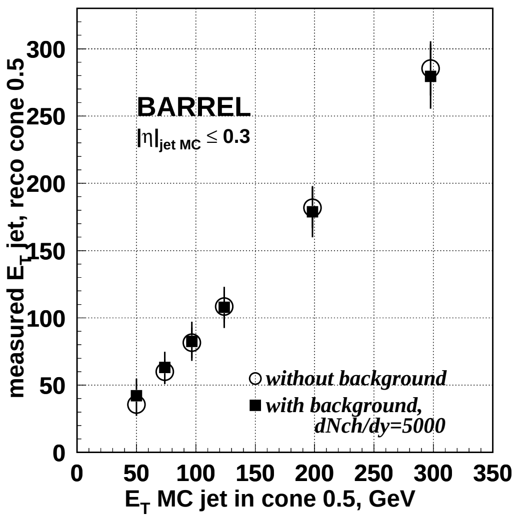

Figure 1. Correlation between reconstructed and generated jet transverse energies.

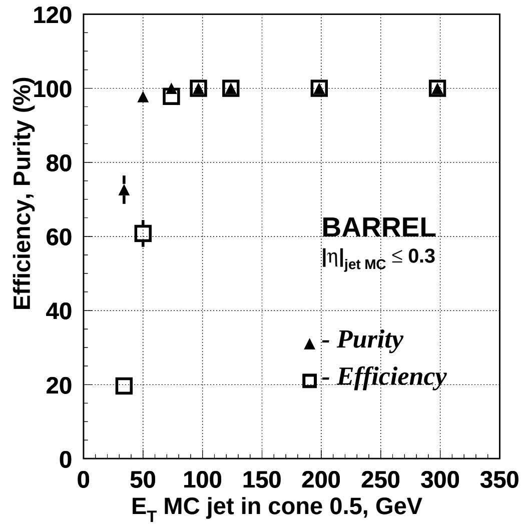

Figure 2. Purity and efficiency of jet reconstruction versus generated jet energy.

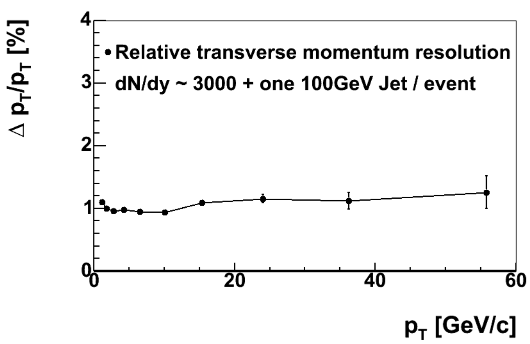

Figure 3. Relative transverse momentum resolution of tracks inside a 100 GeV jet.

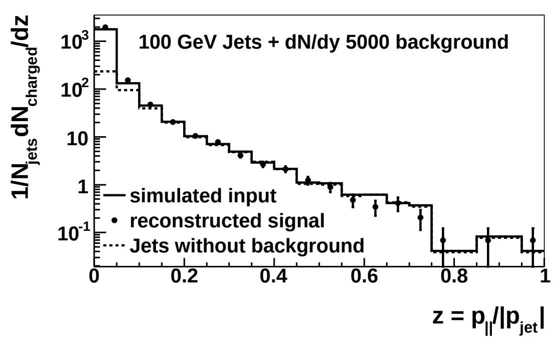

Figure 4. Distribution over momentum fraction z along the 100 GeV jet axis.

finder gives about $\approx 80\%$ reconstruction efficiency and low fake rate even at high track densities of $dN^{\pm}(y=0)/dy = 3000-5000$. The momentum resolution is less than 2% for $p_T < 100$ GeV/c (figure 3). As an example, the reconstructed jet fragmentation function for $E_T^{\rm jet} = 100$ GeV using CMS tracker is shown in Figure figure 4.

6. Monte-Carlo tools to simulate jet quenching

In most available event generators for LHC energies such important medium-induced effects such as jet quenching and elliptic flow are not included or are implemented poorly. Thus, in order to test the sensitivity of LHC observables to QGP formation, and to study the corresponding experimental capabilities of real detectors, the creation of adequate fast Monte-Carlo tools is necessary. One such tool developed recently to simulate rescattering and medium-induced partonic energy loss, is the fast event generator PYQUEN [27], implemented to modify a standard PYTHIA [25] jet event. The code HYDJET merges a fast generator of flow effects [28]

with PYQUEN by simulating full heavy ion events as a superposition of soft, hydro-type state and hard multi-jets. These tools are very useful for detailed testing of the CMS capability to observe various probes of jet quenching and preparations for the heavy ion physics part of CMS Technical Design Report.

7. Conclusions

With its large acceptance, nearly hermetic fine granularity hadronic and electromagnetic calorimetry, and good muon and tracking systems, CMS is an excellent device for the study of medium-induced energy loss by light and heavy quarks ("jet quenching") at the LHC. Adequate jet reconstruction and high-p_T particle tracking with CMS in the high multiplicity environment are possible. Significant progress in development of Monte-Carlo tools to simulate jet quenching in CMS has been achieved.

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